REQUEST FOR A SPECIAL PROJECT 2019–2021

MEMBER STATE: Italy

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Project Title:

REsolved orography impact on the mid-latitude FlOw with EC-Earth (REFOrgE)

If this is a continuation of an existing project, please state the computer project account assigned previously.	**SP** ________________	
Starting year: (A project can have a duration of up to 3 years, agreed at the beginning of the project.)	2019	
Would you accept support for 1 year only, if necessary?	YES ☐	NO ☑

Computer resources required for 2019-2021: (To make changes to an existing project please submit an amended version of the original form.)		**2019**	**2020**	**2021**
High Performance Computing Facility	(SBU)	29,500,000	30,000,000	10,000,000
Accumulated data storage (total archive volume)[2]	(GB)	40,000	55,000	70,000

Continue overleaf

[1] The Principal Investigator will act as contact person for this Special Project and, in particular, will be asked to register the project, provide annual progress reports of the project's activities, etc.

[2] If e.g. you archive x GB in year one and y GB in year two and don't delete anything you need to request x + y GB for the second project year etc.

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Extended abstract

Objectives

Within REFORGE we aim at exploring the impact that resolved and sub-grid orography has on the flow using the EC-Earth global climate model (v3.2.2). Making use of a set of atmosphere-only integrations at three different horizontal resolutions (~80 km, ~40 km and ~25 km) we will 1) explore the effect of resolved orography on the mid-latitude climate – with a special regard to recurrent weather pattern as atmospheric blocking –2) assess to what extent the current parametrizations of sub-grid orographic effects (which are unresolved at a standard climate model resolution, i.e. ~80 km) are able to reproduce the effects of the resolved orography, 3) explore ways of improving the simulation of circulation patterns in climate simulations improving the representation of the unresolved orography.

Introduction

Climate models have shown large improvements in the most recent years. This has been due largely to 1) the constant effort by the modelling community in increasing the fidelity of model physics and reducing systematic biases 2) the enlarged computational power available that allowed for increase in both horizontal and vertical resolution.

However, in some specific regions of the globe large biases still exist. One common example is the representation of the mid-latitude climate, which is affected by complex dynamics which includes barotropic and baroclinic instabilities, large meridional temperature gradients, extra tropical storms and Rossby wave propagation. Among others, one specific weather phenomenon that still puzzles the climate community is atmospheric blocking, especially over the Euro-Atlantic sector.

Atmospheric blocking is a midlatitude weather pattern characterized by a quasi-stationary, long-lasting, equivalent-barotropic, high-pressure system that ‘‘blocks’’ and diverts the movement of the synoptic cyclones (Rex, 1950). Blocking frequencies are usually underestimated by numerical models (Matsueda et al, 2011; Masato et al, 2012; Hamill and Kiladis, 2014; Davini and D’Andrea 2016). The origin of this underestimation in both climate and Numerical Weather Prediction (NWP) models over Europe has been often connected with an incorrect representation of the mean state that affects Rossby waves propagation and consequently blocking dynamics (Scaife et al., 2010). An increase in the horizontal resolution of the atmospheric model has generally been invoked as a solution to improve blocking (Jung et al., 2012, Davini et al., 2017a). Indeed, blocking may benefit of horizontal grid refinement for at least two main reasons: first, this is associated with better resolved transient eddy fluxes, which should sustain the blocking persistence (Shutts, 1983). Second, higher horizontal resolution implies a better resolved mean orography, that can affect the mean state by shaping the planetary waves (Berckmans et al., 2013; Jung et al., 2012).

Recently, Davini et al. (2017a) showed that a high-resolution climate run with EC-Earth (T799, 25km) can attain large improvement in simulating atmospheric blocking when compared to a low-resolution run (T255, 80km). However, they pointed out that a large part of improvements is related to the presence of the more-resolved orography in the high-resolution version, which correctly shaped the mid-latitude flow.

The role of orography and of parametrization of sub-grid orographic effects have recently gained interested of both the NWP and the climate community, in particular due to the results of the

Working Group on Numerical Experimentation (WGNE) Drag project and of several studies focusing on the orographic effects on the flow. The WGNE Drag project showed that NWP and climate models differ not only in the representation of the total subgrid stress but also in the partition between the various drag processes (turbulent drag, orographic form drag, blocking and gravity wave drag), in particular in regions with orography. For instance, Sandu et al. (2016) showed that these inter-model spread in parametrized orographic drag has a large impact on the representation of the wintertime large scale circulation at both medium-range and seasonal time scales. Pithan et al. (2016) showed that removing the blocked flow parametrization from a climate model deteriorates considerably the representation of the mid-latitude flow, leading to a zonalization of the jet-stream. NWP models also differ more than one would expect in the representation of resolved orography and these differences as well have large impacts on weather prediction skill during the NH winter (Sandu et al. 2017). These studies point to the fact that there are still large uncertainties in the representation of orographic drag processes at all time scales, and that these uncertainties have large impacts on the large-scale circulation. They also raise questions as to whether the current parametrizations are able to mimic the effects of the orography on the flow in a realistic manner. Otherwise said, whether the parametrizations induce a circulation response which is similar to that induced by explicitly simulating the orography at high resolution.

Within REFORGE we plan to explore some of these questions focusing on the climate timescales. More precisely, we plan to perform a set of targeted simulations intended to investigate 1) how much of the high-resolution improvements in simulating atmospheric blocking can be related to better resolving the orography, 2) to what extent existing orographic drag parametrizations reproduce the effects on circulation of the resolved orography at climate timescales, 3) how can these parametrizations can be improved in order to increase the fidelity of the representation of the mid-latitude circulation in low-resolution climate simulations.

Methodology

REFORGE will be grounded in a series of high-resolution integrations aiming at assessing the impact of orography on the mid-latitude flow. The idea is to run the high-resolution version of the model with both its standard configuration and an identical one which only differs for the use of a low-resolution orography. REFORGE experiments plan to - in a first order - extend the experiments carried out by Sandu et al. (2017) at climate timescale.

Atmospheric blocking, and more general mid-latitude climate, is characterized by large interannual variability. We thus plan to perform long integrations trying to minimize the impact of external forcing: we will use fixed boundary conditions, i.e. climatological SSTs as well as a constant solar and greenhouse gases (GHG) forcing. However, long integrations will be needed in order to overwhelm the internal variability of the mid-latitude climate: we plan thus to run experiments of 60 years each.

The first part of REFORGE will be characterized by a group of key simulations (**CORE** hereafter) that will include:

1) 60 years at the EC-Earth standard resolution, TL255L91.

2) 60 years at the EC-Earth high resolution, TL511L91.

3) 60 years at the EC-Earth ultra-high resolution, TL799L91.

4) 60 years at TL511L91 using the orography from TL255L91.

5) 60 years at TL799L91 using the orography from TL255L91.

By comparing those simulations will be possible to assess the direct effect of horizontal resolution on the representation of the midlatitude climate and to evaluate the direct impact of resolving orography on the atmospheric flow key features.

Atmospheric blocking and other elements of the mid-latitude climate variability will be evaluated using the Mid-Latitude Evaluation System (MiLES) package (Davini et al, 2018), which includes different diagnostic for atmospheric blocking, weather regimes and teleconnection patterns on the Northern Hemisphere climate.

Once this first part is concluded, a group including several sensitivity experiments (**SENS** hereafter) with the low-resolution (TL255L91) model will be carried out in order to investigate the properties of orography, following always 60 years of simulation.

These experiments will develop mainly along two streams: 1) what is the respective role of the different components of the sub-grid orography parametrization currently used in EC-Earth (which is still based on the scheme by Lott and Miller, 1997) 2) which spectral part of the resolved orography is most effective in shaping the atmospheric flow (following the experiments by Tibaldi, 1986).

Other configurations may be envisaged during the exploration of the different setups. Furthermore, additional sensitivity experiments will be designed in collaboration with ECMWF and MetOffice which are currently investigating the effect of the resolved and parametrized orography on atmospheric circulation at medium-range scale. According to the results of the **SENS** experiments, REFORGE aims at finding a new configuration for sub-grid orography able to improve the current representation of atmospheric blocking and other mid-latitude atmospheric patterns at low resolution (TL255L91).

Therefore, a final set of simulations (**CPL** hereafter) will include 3 ensemble members of 65 years (1950-2015) each of coupled runs with the coupled version of EC-Earth at low resolution (TL255L91-ORCA1L75) in a configuration similar to the one that will be used for the upcoming CMIP6 project. This will be compared against a twin simulation that will exploit of the most improved orography configuration found within the **SENS** experiments, in order to verify the robustness of the potential improvement.

We will organize our workplan in detail as follows:

- **Month 1-2**: Transfer of initial conditions and set up of the experiments for all resolutions. First test experiments will be run.
- **Months 2-4**: Running of the **CORE** TL255 simulations
- **Months 4-12**: Running of the **CORE** TL511 simulations.
- **Months 8-16**: Running of the **CORE** TL799 simulations and first analysis of the results.
- **Months 12-28**: Running of the **SENS** simulations.
- **Months 28-32**: Running of the **CPL** simulations.
- **Months 33-36**: Risk management: eventual re-run of failed experiments.
- **Months 4-36**: Post-processing of the raw model outputs and preliminary analysis. This phase will start early during the project in order to minimize the intermediate storage at the production machine.
- **Months 4-36**: Transfer of post-processed model output.

Resources and technical requirements

EC-Earth code has been already successfully implemented and tested on different supercomputing platforms by groups participating in the consortium, including CCA at ECMWF (UK). This should minimize the time needed for the setup of the machine. The proponent group at ISAC-CNR has a wide experience on this kind of global climate simulation: it has implemented and used EC-Earth v3 also on supercomputing platforms as the Supermuc at LRZ (Germany) and Marconi at CINECA (Italy). Data storage and post-processing is planned to be performed at the same time of running experiments. EC-Earth has already been at the core of the Climate SPHINX project (Davini et al. 2017b) and has participated in ECMWF special project SPLTUNE.

The total number of **CORE** integrations will include 60 years at T255L91, 120 years at T511L91 and 120 years at T799L91. The **SENS** runs at T255L91 will be about 620 years. These can be split into 20 test years + (10 different orography configurations) * (60 years) = 620 years for the core simulations.

Finally, we will add 390 years of **CPL** simulations at low resolution, that can be split in three ensemble members each for the standard and updated configuration. The integrations will last 65 years with historical forcing from 1950 up to 2015. The three ensembles will allow for a robust comparison among the two configurations even considering the large interannual variability that characterizes atmospheric blocking.

Scaling tests performed on CCA at ECMWF (in the framework of the SPITDAVI special project) have determined that in the following EC-Earth configuration is optimal:

- **TL255L91:** 287 cores for IFS and one for the AMIP reader (total 288, i.e. 8 nodes). One year of simulation is completed in about 3h, resulting in about 14,000 SBUs/year.
- **TL511L91**: 539 cores for IFS and one for the AMIP reader (total 540, i.e. 15 nodes). One year of simulation is completed in about than 12 hours, resulting in about 105,000 SBUs/year.
- **TL799L91:** 899 cores for IFS and one for the AMIP reader (total 900, i.e. 25 nodes). One year of simulation is completed in about 23 hours, resulting in about 335,000 SBUs/year.
- **TL255L91-ORCA1L75**: the coupled runs will require 286 cores for IFS, 1 for the runoff mapper, 1 for XIOS and 108 cores for NEMO (total 396, i.e. 11 nodes) in about 3h of simulations, resulting in about 19,500 SBUs/year

This number can be increased or reduced if at the moment of need we will be concerned or not by the wall time of the simulations. Following these figures, the following requirements emerge:

- **CORE runs:** 850,000 SBUs for TL255, 12,500,000 SBUs for the TL511 and 40,000,000 SBUs for the TL799 for a total of 53,350,000 SBUs
- **SENS runs:** 8,700,000 SBUs
- **CPL runs**: 7,500,000 SBUs

The total requirement will be **69,500,000 SBUs** over three years.

Automatic postprocessing routines following the CMOR standard will be implemented in order to make the data available for data analysis. However, during the 3 years of the project raw data output will be archived as a backup. Our estimates of storage requirements are around 26 GB/model-year at TL255L91, increasing to about 30 GB/model-year in coupled mode. This will include the restart files and outputs at 6-hours frequency on multiple pressure levels. About a 90 GB/model-year will be needed for the T511L91 configuration and about 250 GB/model-year for the T799L91. Overall, at the moment of maximum occupancy, the required archive space will be around 70 TB.

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